ACACIA TUMIDA PRUNINGS AS SOURCE OF NUTRIENTS FOR SOIL FERTILITY IMPROVEMENT IN NIGER: BIOCHEMICAL COMPOSITION AND DECOMPOSITION PATTERN

BY

ILIASSO ABOUBACAR DAN KASSOUA TAWAYE

(ENGINEER IN AGRONOMY)

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ACACIA TUMIDA PRUNINGS AS SOURCE OF NUTRIENTS FOR SOIL FERTILITY IMPROVEMENT IN NIGER

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IN

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BY

ILIASSO ABOUBACAR DAN KASSOUA TAWAYE

(ENGINEER IN AGRONOMY)

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DECLARATION

I, hereby declare that this submission is my own work towards the MPhil degree and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgment has been made in the text.

Aboubacar Dan Kassoua Tawaye Iliasso ……................. .... ……….................

(Student) **20357397** Signature Date

Certified by:

Dr. Nana Ewusi Mensah ….................... ……………………

(Principal Supervisor) Signature Date

Prof. Robert C. Abaidoo ………................ ....…………….

(Co-supervisor) Signature Date

Dr. Doubgedji Fatondji ………................ ....……………

(Co-supervisor) Signature Date

Certified by:

Dr. Enoch A. Osekre ………................. ....…………….

(Head of Department) Signature Date

DEDICATION

To my late father, my mother and all those who in diverse ways have added value to my life.

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ABSTRACT

Limited sources of organic amendments for increasing nutrient availability for crop growth is a major challenge in Niger. Reports on the role of organic material in soil fertility improvement in the Sahelian zone of Niger have been focused merely on limited range of organic amendments such as animal manure and crop residues. There is however little information on the use of agro-forestry leaves for soil fertility improvement in Niger. The current study was therefore designed to (i) evaluate the quality of *Acacia tumida* prunings, (ii) determine the decomposition and nutrient release patterns of *Acacia tumida* prunings (iii) assess the factors that influence the decomposition and nutrient release patterns of organic materials under Sahelian conditions. Litterbag experiment was conducted in a Randomized Complete Block Design (RCBD) with three replications. The treatments consisted of a factorial combination of (a) three types of organic amendments (*Acacia tumida* pruning, millet straw and cattle manure), and (b) two levels of insecticide application (with and without insecticide). The litterbag experiment was conducted on sandy and crusted sandy soil types. The percentage composition of N, P and K in *Acacia tumida* prunings were 2.30, 0.14 and 1.50, respectively on a dry weight basis. The decomposition of *Acacia tumida* pruning was faster (*k/day* = 0.014) than that of cattle manure *(k/day* = 0.012). On the average, 45 and 34 % of organic materials decomposed in the litterbags free of insecticide and litterbags treated with insecticide respectively. The contribution of termites to organic amendment decomposition was estimated to be 36 % for millet straw and 30 % for manure.

The highest N release constant (*k/day* = 0.025) was recorded for millet straw whereas the highest P release constant (*k/day* = 0.035) was documented for manure. The highest potassium release constant (*k/day* = 0.114) was recorded for *Acacia tumida*

pruning. This study has contributed to knowledge regarding the decomposition of *Acacia tumida* prunings which has an important implication for diversifying the source of nutrients for soil fertility improvement in Niger. Moreover, the results of this study indicate that the presence of termites and the intrinsic quality of the organic material play crucial roles in the decomposition of organic materials in the Semi-arid environment of Niger.

CHAPTER ONE

1. 0 INTRODUCTION

Agricultural production in Niger is predominantly rain-fed cereal-based cropping systems characterized by low yields as a result of low soil fertility (Gandah *et al.,* 2003). The application of mineral fertilizers on staple food crops is generally restricted due to the limited financial resources available to smallholder farmers (Abdoulaye and Sanders, 2005). The lack of sufficient income prevents the majority of the smallholder farmers to replace soil nutrients exported with harvested crop products which consequently leads to the decline in soil fertility and thereby decrease crop yields (Sanchez *et al.,* 1997). Organic resources (crop residues and animal manure) are often promoted as alternatives to mineral fertilizers (Schlecht *et al.,* 2006). However, the availability of organic materials for use as soil amendments on most farms is a challenge because of insufficient quantities (animal manure) and other competitive uses (crop residues) such as animal grazing, fencing of houses and firewood (Bationo *et al.,* 1998; Valbuena *et al.,* 2015). For increased crop yields in the smallholder cropping systems, there is therefore a need to diversify the sources of organic materials for soil fertility maintenance particularly in Niger where the parkland is characterized by the presence of shrubs growing in the farmers fields (Schlecht *et al.,* 2006).

The use of agro-forestry trees for mulching could be a possible option to overcome the limited availability of organic amendments in Niger because of their capacity to provide biomass for mulching. However, this option is not generally well explored because of limited availability of agro-forestry trees. Recently, some agro-forestry technologies have been developed by the International Crop Research Institute for the Semi-arid Tropics (ICRISAT) which include alley cropping systems in which trees including *Acacia tumida* are intercropped with annual crops (Fatondji *et al.,* 2011; Pasternak *et al.,* 2005).

Acacia tumida, is one of the agro-forestry Australian *Acacias* introduced and tested in Niger since 1980 with a primary aim to improve food security and combat hunger through the use of their seeds which are rich in protein and other nutrients (Rinaudo *et al.,* 2002). This species produces good seed yield and provides other products and services such as soil fertility improvement through nitrogen fixation and leaves for mulching. *Acacia tumida* tree is pruned once a year (with a total foliar biomass of 8 Mg ha^{-1}) and the prunings also add organic matter and nutrients to the soil (Rinaudo and Cunningham, 2008). However, little is known about the potential of the residues of this agro-forestry tree as a nutrient source for improving soil fertility and crop yields.

There is increasing evidence that the quality of organic material added to the soil determines its contribution to crop growth when applied to the soil (Giller and Cadisch, 1997; Palm *et al.,* 2001). Yet, for an organic resource to achieve this role, its degree of decomposition over the peak nutrient requirement of the crop is essential. Organic material decomposition is one of the utmost important processes in the biosphere as it controls nutrient release for plant growth (Li *et al.,* 2011; Manlay *et al.,* 2004). There is therefore the need to determine the decomposition and nutrient release patterns of *Acacia tumida* prunings for better management of nutrient supplies for the benefit of crops.

On the other hand, the rate and pattern of decomposition and mineralization of an organic material incorporated into soil depends on the interaction between its quality and the prevailing chemical and physical environment of the soil, and also the community of the decomposers (Beare *et al.*, 1992; Bending *et al.,* 2004). Earlier studies established that, decomposition is also influenced by climate, and the activity of meso and micro-fauna (Swift *et al.,* 1979). It is generally known that under dry environmental conditions such as prevalent in Niger, the overall microbial activity is low (Coyne, 1999). In studying the contribution of termites to the breakdown of straw under Sahelian conditions, Mando *et al.* (1996) reported that termites are an alternative option for improving soil structure in semi-arid regions.

Termites have been advocated to play a key role in nutrient recycling (Basappa and Rajagopal, 1990; Freymann *et al.,* 2010). In the Sahel, termites can exert a robust influence on organic residue breakdown to overcome the restraining effects of climatic and edaphic conditions, and thereby control the dynamics of organic matter and nutrients (Mando, 1998). In addition to comminution effect of termites on organic material losses, which favours microbial degradation, termite species play a major role in enhanced symbiosis with fungus (*Termitomyces* spp.), which is essential for the decomposition of poor quality plant material (Freymann *et al.*, 2008; Mando and Brussaard, 1999). Esse *et al.* (2001) reported that macro-organisms such as termites play a dominant role in the initial phase of manure decomposition. Furthermore, Fatondji *et al.* (2009) reported a lower initial decomposition rate of millet straw as a result of the lower nutrient content and a preference of the termites for manure compared with millet straw. However, in Burkina Faso, Ouédraogo *et al.* (2004) reported a preference of termites for maize straw compared to manure.

Most decomposition studies (Aerts and de Caluwe, 1997; Palm *et al.,* 2001) focused on the identification of general chemical predictors of organic material decomposition, and suggest that organic material decomposition rate is regulated by a wide variety of material quality (e.g. biochemical composition of the material).

However, in the Sahelian zones, several studies have reported seasonal differences in the decomposition and mineralisation of applied organic material, which are attributable to diverse factors including variations in soil temperature, rainfall and soil moisture rather than the quality of the applied organic amendment. Tian *et al.* (1997a) reported that in the dry areas, low quality residues decompose faster than high quality residues which imply the direct correlation between decomposition rate and quality of material in areas where moisture is not a limiting factor. There is therefore a need to establish the determinants of organic amendments decomposition particularly *Acacia tumida* pruning in dry environments such as Niger and also to determine whether the biochemical qualities of *Acacia tumida* pruning or the presence of macro-organisms (termites) have significant influence on its decomposition rate.

The overall objective of this study therefore was to explore the diverse sources of organic materials for soil fertility improvement and contribute to a better understanding of the determinants of *Acacia tumida* prunings decomposition in Niger. The specific objectives were to:

1. determine the biochemical qualities of *Acacia tumida* prunings;
2. evaluate the decomposition and nutrient release patterns of *Acacia tumida* prunings relative to other organic materials (animal manure and millet straw) commonly used for soil fertility improvement in Niger;
3. assess the contribution of termites to the decomposition of *Acacia tumida* prunings;
4. evaluate the effect of soil type on the decomposition of *Acacia tumida* prunings.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Definition of decomposition

Decomposition is defined as a biological process that includes the physical breakdown and bio-chemical transformation of any dead plant or animal material into simpler organic and inorganic molecules, directly usable by micro-organisms and plants (Bot and Benites, 2005). It can also be considered as the process by which a given organic material decomposes as a result of the interactions of physico-chemical and biological factors such as climate, soil properties, the supply of oxygen, moisture, and available minerals, and the C/N ratio of the added material, the microbial population, the age and lignin content of the added residue (Duong, 2009). Giller and Cadisch (1997) defined the concept organic amendment breakdown as the rate of change of any non-living organic resource over time.

2.2 Organic material quality and decomposition

Several studies have shown that the transformations of dead organic materials into plant accessible nutrient forms by the decomposing community (bacteria and other organisms), are dependent on the quality of organic material. According to Tian *et al.* (1997b), the decomposition of organic material is related to their C/N ratio, lignin and polyphenol contents. Bayala *et al.* (2005) argued that the initial nutrient (N, P, K) and cellulose content of an organic material have an influence on the decomposition rates. The same authors reported that, for example *Parkia biglobosa* leaves decompose faster than *Vitellaria paradoxa* leaves as a result of their initial low N and high polyphenol content. In other studies, Mafongoya *et al.* (1997) reported that an organic amendment with a high C/N ratio is more recalcitrant in decomposition than the organic material with a low C/N ratio. According to Ostertag and Hobbie (1999), increased initial content of N and P could stimulate litter decomposition. Further, Jensen (1997) and Soon and Arshad (2002) clearly demonstrated that the initial nitrogen and phosphorus content were good indicators for residue decomposition rates. However, the breakdown of organic material is also dependent on the microbial and termites activity and soil moisture content (Six *et al.*, 2004). On the other hand, Recous *et al.* (1995) reported that the quantities of lignin and cellulose in plant residue are also important in predicting rates of decomposition. According to these authors, slow rates of decomposition are commonly observed with residues with high lignin and cellulose contents.

Earlier studies on the decomposition and nutrient release patterns focused mainly on the universal determinants (e.g. biochemical properties) controlling decomposition and nutrient release patterns from an organic material (Giller and Cadisch, 1997; Palm and Sanchez, 1991; Swift *et al.*, 1979). The general conclusions from these studies were that the organic material with high quality properties decomposed faster than that of low quality properties. Tian *et al.* (2007) reported that in the dry areas, low quality residues decomposed faster than high quality residue which implied that the direct correlation between the decomposition rate and the quality of material was valid only in areas where moisture was not a limiting factor. There is therefore the need for exploring other potential factors that govern the decomposition and nutrient release patterns of an organic amendment under the dry conditions of Niger with special focus on the comminution effect of soil macro-fauna such as termites.

2.3 Factors affecting the decomposition of organic material

According to Duong (2009), the rate of decomposition and nutrient release of organic amendments under field conditions were regulated by the combination of three interacting factors: (1) physical and chemical properties of organic amendments, (2) physical and chemical environment (location, soil properties, and climate), and (3) decomposer community (micro-organisms).

2.3.1 Physical and chemical properties of organic amendments

The physical properties of organic amendments have an important influence on their decomposition (Bending *et al.*, 2004). The reduction in organic material particle size increases the surface area available for colonization by soil micro-organisms and thereby increases their decomposition compared with an organic amendment with a large particle size (Duong, 2009; Ewusi–Mensah, 2009).

The chemical properties of organic materials are influential in the evaluation of residue decomposition (Van Veen *et al.*, 1984). Soon and Arshad (2002) showed that the decomposition rate of pea was faster than canola and the latter decomposed faster than wheat due to their high N content and low C/N ratio of wheat. In another study, Fatondji *et al.* (2009) showed that the low initial N content of millet straw and its high C/N ratio restricted its decomposition compared with manure which had a relatively high N content and low C/N ratio. In addition, Cobo *et al.* (2002) showed that the decomposition of organic materials in the soil depends on their C/N ratios and the duration of the decomposition process. Thomas and Asakawa (1993) reported that the decomposition of the organic materials is controlled by their chemical characteristics including N concentration, C/N ratio and lignin/N ratio.

The concentration of lignin in an organic material reduces the role of decomposition by making the cell walls hardly decomposable by micro-organisms (Berg and McClaugherty, 2003). Duong (2009) has reported a low decomposition of organic material and slow mineralization of N with an increasing concentration of lignin. According to Palm and Sanchez (1991), the initial polyphenol in the organic materials residues also influenced the rate of decomposition of organic materials.

2.3.2 Physical and chemical environment

Kumar (2007) reported that soil physical and chemical conditions are the key factors that control litter decomposition. Soil properties and climate conditions are the most influential physical and chemical environment that control the decomposition of organic material (Swift *et al.*, 1979). The physical properties of the soil such as temperature and moisture as well as its chemical condition such as pH and nutrient contents are among the factors which affect crop residue decomposition (Arthur, 2009).

2.3.2.1 Soil properties

2.3.2.1.1 Soil clay content

The soil clay content is one of the major soil texture components that influences sources of soil aeration and therefore significantly determine the decomposition rates of the organic amendments by increasing the availability of oxygen for the aerobic micro-organisms (Sylvia *et al.,* 2005). According to Epstein *et al.* (2002), the decomposition rate of soil organic matter increased as soil clay content decreased. Clay concentration is positively correlated with aggregate size and aggregate formation and it was found to correlate negatively with potential N mineralization (Sylvia *et al*., 2005). Hassink *et al.* (1991) reported that the net mineralization of soil organic matter was more rapid in sandy soils than in clay soils due to a greater degree of physical protection of soil organic matter in the clay soils. Saidy *et al.* (2015) revealed by analyzing sand-clay mixtures supplemented with an OM solution that the organic C mineralization was significantly affected by clay mineralogy. The current knowledge about the effect of clay content on the storage of OM is based on limited and conflicting data but, direct studies on the effect of clay on soil OM dynamics are rare (Feng *et al.*, 2013). This raises the question whether the clay mineralogy affects the decomposition, and amount of nutrient released of organic materials.

2.3.2.1.2 Soil aeration

Duong (2009) reported that an adequate soil aeration accelerates the decomposition of the organic amendment and the growth of micro-organisms. Oxygen supply is essential to aerobic micro-organisms, the primary agents in decomposition (Berg and McClaugherty, 2003). The availability of oxygen in sufficient quantity stimulates soil organisms to convert organic compounds into inorganic compounds (Uren, 2007). Furthermore, Kundu (2013) reported that oxygen is required for respiration of all aerobic organisms to achieve the most efficient form of metabolic activity. Berg and McClaugherty (2003) reported that under sufficient oxygen condition, aerobic micro-organisms including bacteria will be active and grow rapidly, consuming more organic material and thereby increasing the availability of nutrients for plant growth.

2.3.2.1.3 Soil pH

According to Mengel *et al.* (2001), the occurrence and the activities of soil micro-organisms can be influenced by the soil pH and eventually affect both organic matter decomposition and nutrient availability. Soil pH influences organic amendment decomposition processes due to its effect on microbial activity (Duong, 2009).

Microbial populations seemed to be highest in soils with a neutral pH that was more conducive to decomposition than acidic or alkaline soils. In studying the microbial community composition and functioning in the rhizosphere in three Banksia species in native woodland of Western Australia, Marschner *et al.* (2005) showed that the soil pH influences microbial community composition more strongly than other soil properties. The optimum pH for maximum decomposition by micro-organisms range from 6 to 7.5 (Kalshetty *et al.,* 2015). Although, the importance of soil pH for soil micro-organisms activities is well documented, there is however few studies that have assessed the effects of soil pH on the decomposition of organic amendments particular in the Sahelian dry zones where the soil microbial activities seem to be minimal as a result of restricted soil moisture content. Knowledge on the interacting effects of soil pH and soil moisture conditions would have important implications on the soil microorganisms responsible for nutrients cycling.

2.3.3 Climate

2.3.3.1 Temperature

Temperature is one of the important environmental physical factors that determine how rapid organic amendments are metabolized and subsequently mineralized. Duong (2009) reported that temperature is a key factor controlling the rate of decomposition of organic amendments. It appears that microbial activity increases with increasing level of temperature at an optimal of 30 - 45 °C (Berg and McClaugherty, 2003). González and Seastedt (2000), reported that decomposition processes are faster in the tropics because of higher temperatures compared with the temperate regions. According to Liang *et al.* (2003) the range of the temperatures for maximum decomposition vary from 50 to 60 °C.

2.3.3.2 Soil moisture content

Brockett *et al.* (2012) reported that soil moisture seems to be the most important climatic factor that influences the decomposition of organic material. Pausch *et al.* (2013) earlier reported that water availability could influence the rate of litter decomposition and nutrient release. Under the Sahelian conditions, Fatondji *et al.* (2006) demonstrated that more moisture collected through the water harvesting techniques enhanced the decomposition of manure and millet while Tian *et al.* (2007) showed that the N release from high quality residues such as *Gliricidia sepium* decreased from the humid zones to the arid zones of West Africa.

2.3.4 Soil organisms

Several studies have shown that the presence of soil fauna increases the rates of leaf litter decomposition (Hättenschwiler and Gasser, 2005; Irmler, 2000). When soil fauna were excluded, organic material remaining was up to 99 % for recalcitrant organic material compared with less than 20 % in the presence of soil fauna (Riutta *et al.,* 2012; Vasconcelos and Laurance, 2005). According to Ouédraogo *et al.* (2004), the disappearance of recalcitrant organic material was apparently not effective in one year in the absence of soil fauna, particularly in the arid conditions. Organic material decomposition in semi-arid zone is mediated by soil micro-organisms and macro-fauna such as termites which play dominant role in the decomposition. Termites represent as much as 65 % of soil fauna biomass in soils of dry tropical Africa (Jouquet *et al.,* 2011). According to Mando (1997), termites improve soil physical properties within a short time and also could be responsible for up to 80 % of litter mass losses in one year under the dry conditions of the Sahel.

2.4 Summary of literature review

It is apparent from the literature reviewed that several studies have been done to establish the decomposition and nutrient release patterns of organic materials and the influential factors that affect these patterns. However, there is little information on the decomposition and nutrient release patterns from organic materials in Niger. Furthermore, the limited information that exists, focus mainly on the limited range of organic materials such as animal manure and crop residues. There is however, limited information about the decomposition and nutrient release patterns of existing agro-forestry trees in Niger. Moreover, the determinants of organic material decomposition under the dry conditions of Niger are not yet fully explored. This current study aims therefore at addressing these knowledge gaps.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the study area

The field experiment was conducted from June 2014 to December 2014 at ICRISAT-Sadoré Research Station located between 13°15'N latitude and 2°18'E longitude. The Research Station is situated at 40 km South-East of the capital city of Niger, Niamey (Fig. 1).

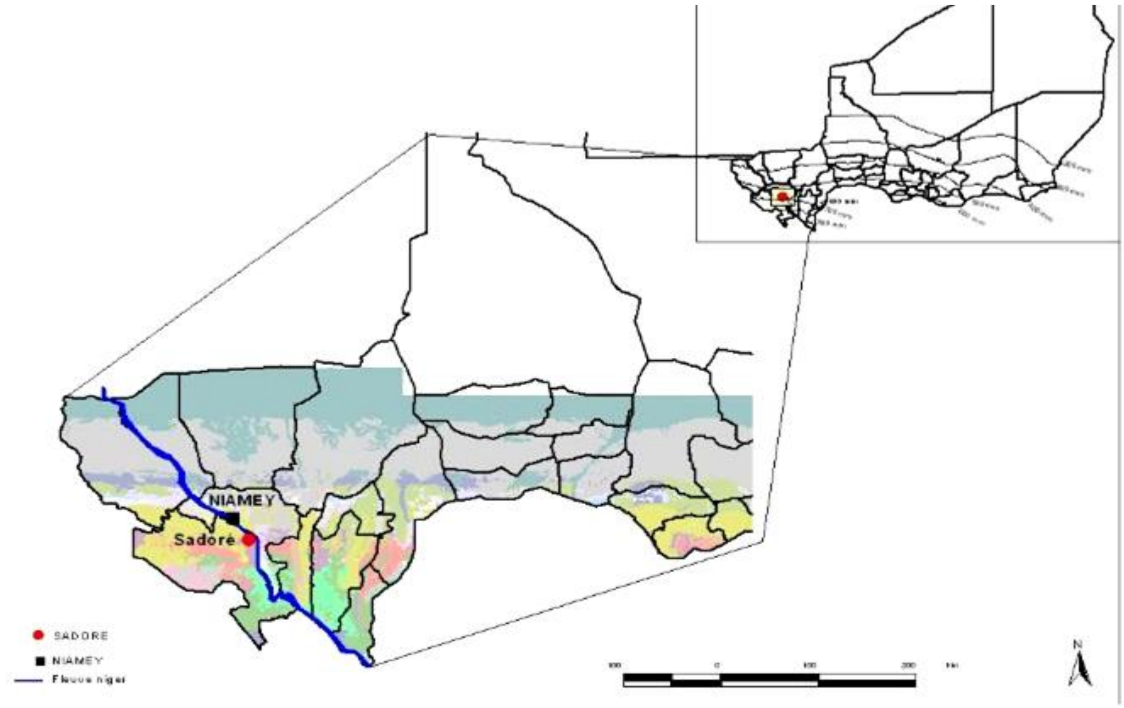

Figure 1: Location of ICRISAT - Research station in Sadoré-Niger

3.1.1 Climate of the study area

The climatic conditions in Sadoré are characterized by a mono-modal rainy season which occurs generally from June to September followed by a long dry season which triumphs in all the rest of the year (Sivakumar, 1988). The long-term annual mean rainfall is 550 ± 110 mm (ICRISAT–Climate database, 2014) and the temperature varies between 25 and 41 °C. The potential evapo-transpiration is 2000 mm per year (Sivakumar *et al.,* 1993).

3.1.2 Soil of the study area

The soil is Arenosol (World Reference Base, 2006), classified as sandy, siliceous, isohyperthermic psammentic Paleustalf according to the US soil taxonomy (Buerkert *et al.,* 1998). This soil is generally acidic with relatively high aluminum saturation (Fatondji *et al.*, 2006).

3.1.3 Vegetation of the study area

Vegetation type is Sahelo-Sudanian, composed of bushes and grasses with some tree species. The natural vegetation of Sadoré is characterized essentially by shrubs including *Guiera senegalensis, Prosopis africana, Anona senegalensis,* trees such as *Combretum glutinosum, Balanites aegyptiaca, Parkia africana, Sclerocarya birrea, Faidherbia albida, Piliostigma reticulatum* and herbaceous perennials including *Eragrotis tremula, Andropogon gayanus, Cenchrus biflorus* (Alumira and Rusike, 2008).

3.2 Experimental design

The litterbag experiment was arranged in a Randomized Complete Block Design (RCBD) with three replications. The treatments consisted of the factorial combination of (a) three types of organic amendments (*Acacia tumida* pruning, millet straw, and cattle manure), (b) insecticide application at 2 levels (with and without insecticide). The combination of these factors, gave a total of six treatments described as follows:

1. T_1: millet straw without insecticide;
2. T_2: manure without insecticide;
3. T_3: *Acacia tumida* pruning without insecticide;
4. T_4: millet straw with insecticide;
5. T_5: cattle manure with insecticide;
6. $T_{6:}$ *Acacia tumida* pruning with insecticide.

In order to assess the effects of soil type on the decomposition of organic materials, the same treatments were applied at two locations (ICRISAT, Research Station and in the Sadoré village) characterized by different soil textures (sandy soil and crusted sandy soil).

The choice of organic materials used in this study was justified by the importance of these materials in the maintenance of soil fertility in Niger. The millet straw was collected from the last harvest at the ICRISAT Research Station while the cattle manure was collected from a barn in the Sadoré village. *Acacia tumida* pruning was collected from the *Acacia tumida* trees grown in the field trial at the ICRISAT before the onset of the rainy season. The insecticide treatment was applied to control the presence and activities of termites in the litterbags.

Fifty grams of each of sun-dried organic material (*Acacia tumida* pruning, millet straw and cattle manure) were placed into the litterbags. The litterbags of 20 cm x 20 cm in size were made up of an iron net of 2 mm mesh size. A total of twelve (12) litterbags of each organic amendment treatment were placed in each replication.

3.2.1 Characterization of organic materials

In order to appreciate the quality of different organic materials used in the current study, samples of the sun-dried materials were collected. The samples were ground and passed through a 2 mm mesh sieve. Three well mixed sub-samples of each organic material (*Acacia tumida* pruning, millet straw and cattle manure) were taken separately to the laboratory to analyze for the following parameters: total nitrogen, organic carbon, total phosphorus, polyphenol, lignin, total potassium. All these parameters were determined using appropriate laboratory procedures as described below.

3.3 Litterbag sampling

Litterbags were collected at three (3) weeks intervals from the field. At each collection date of 3, 6, 9, 12, 15 and 18 weeks after decomposition, two litterbags of each organic amendment treatment were collected and sun-dried after which soil was carefully brushed off and the remaining organic amendment oven-dried at 55 – 60 °C for 48 hours. The remaining dry material was then weighed. The percent weight of organic amendment remaining was calculated using the formula below:

$$\%\ \text{Dry weight remaining} = \frac{DW_t}{DW_i} \times 100$$

where:

$\boldsymbol{DW_t}$ = mean oven weight at time t

$\boldsymbol{DW_i}$ = initial oven dry weight

To estimate the nutrients released at a particular date (corresponding to the litterbag collection), the samples of remaining organic material at these sampling times were ground and passed through 2 mm mesh sieve for N, P and K analyses. The details of methods for the N, P and K concentrations are described below. The nutrient release was calculated as the difference between the initial nutrient content in the organic material and the quantity remaining at the sampling period.

3.3.1 Determination of physical and chemical characteristics of soils of the experimental fields

Before the onset of the experiment, composite soil samples were collected at 0-10 cm and 10 - 20 cm depth in the two experimental fields using an aluminum tube. The samples were placed in plastic bags. After drying, the soil samples were sieved through a 2 mm sieve. The chemical and physical properties of these samples were determined according the following laboratory procedures.

3.3.1.1 Soil pH

The pH was potentiometrically measured in the suspension of a 1:2.5 soil: water mixture (Van Reeuwijk, 1993). Ten gram (10 g) portion of soil was weighed into a beaker and 25 mL of distilled water was added. The suspension was stirred mechanically and allowed to stand for 30 minutes after which the pH in water was measured. Before the measurements; the pH meter (Hanno Instruments Ltd, Corrollton, Texas) was calibrated using buffer solutions of pH 4 and 7.

3.3.1.2 Soil total nitrogen

Total nitrogen was determined by the Kjeldahl digestion and distillation method as described by Houba *et al.* (1995). A 1.0 g portion of soil was put into a Kjeldahl digestion flask of 75 mL and then 2.5 mL of Kjeldahl catalyst (mixture of 1 part

Selenium powder + 10 parts $CuSO_4$ + 100 parts Na_2SO_4) were added and mixed carefully. The stirred mixture was placed on the hot plate and heated to 100 °C for 2 hours. The flasks were removed from the plate and allowed to cool after which, 2 mL of H_2O_2 were added and the mixture was heated again at 330 °C for four hours until clear and colourless digest was obtained. The volume of the solution was made up to 75 mL with distilled water. Clear aliquot of the sample and blank were pipetted and put into auto-analyser Technicon AAH (Pulse Instruments Ltd, Saskatoon, Canada) for the determination of total nitrogen. The percent total nitrogen was calculated as follows:

$$\% \text{ Total N} = \frac{(a - b) \times 75}{\text{weight of sample } (g) \times 10000}$$

where:

a = N content of the soil sample

b = N content of the blank

10000 corresponds to the coefficient of conversion from ppm N to percent N

75 mL = final diluted volume of digest

3.3.1.3 Soil available phosphorus

Soil available phosphorus was determined by the Bray No.1 method (Bray and Kurtz, 1945) as described by Van Reeuwijk (1993). Four gram portion of air-dried soil (2 mm sieved) was weighed into flasks of 100 mL volume (two blanks and a control soil sample were included) and 14 mL of Bray No.1 solution (*0.03 M* NH_4F and *0.025 M* HCl) were added. The mixture was then shaken for 5 minutes on a mechanical shaker, allowed to stand for 2 minutes and then centrifuged for 5 minutes at 3000 rpm and filtered through a Whatman N°. 42, filter paper. Five millilitre (5 mL) portion of the solution (sample) was pipetted into a volumetric flask of 25 mL followed by the addition of four (4) mL of ascorbic acid solution and mixed thoroughly. The volume of the solution was made up to 25 mL with distilled water, after which the solution was allowed to stand for at least an hour for the blue colour to develop to its maximum. Standard series containing 1.2, 2.4, 3.6, 4.8, 6.0 mg L^{-1} P were also prepared and treated similarly. The absorbance was measured on the spectrophotometer (Wagtech Projects, Ltd, UK) at 882 nm. The extractable P (mg/kg soil) was calculated as follows:

$$\mathbf{P} = \left(mg\ kg^{-1}\ soil\right) = (\boldsymbol{a} - \boldsymbol{b}) \times \frac{\mathbf{14}}{\boldsymbol{s}} \times \boldsymbol{mcf}$$

where:

a = mg L^{-1} P in the sample extract

b = mg L^{-1} P in the blank

S = air-dry weight of the soil sample in gram

mcf = moisture correction factor

3.3.1.4 Soil organic carbon

Organic carbon content of soil was determined using *Walkley-Black* procedure described by Van Reeuwijk (1993). This involves a wet combustion of organic matter with the mixture of potassium dichromate ($K_2Cr_2O_7$) solution and sulphuric acid. Five gram (5g) portion of air-dried soil was weighed in 500 mL Erlenmeyer flask and 10 mL of *0.1667 M* potassium dichromate ($K_2Cr_2O_7$) solution were added and the mixture stirred gently to disperse the soil. Then, twenty millilitres (20 mL) of concentrated H_2SO_4 (95 %) were added to the suspension which was shaken gently and allowed to stand for 30 minutes on an asbestos sheet. Thereafter, 250 mL of distilled water was added. This was followed by the addition of 10 mL of concentrated (85 %) orthophosphoric acid (H_3PO_4) and 1 mL of diphenylamine indicator. The suspension was titrated with *1.0 M* $FeSO_4$ until the colour changed to blue and then to a pale green end-point. A blank was included and treated in the same way. The percentage organic carbon (OC) was calculated as follows:

$$\% \text{ OC} = M \times \left(\frac{V_1 - V_2}{S}\right) \times 0.39 \times mcf$$

where:

M = molarity of $FeSO_4$ (from blank titration)

V_1 = volume of $FeSO_4$ required for the blank,

V_2 = volume of $FeSO_4$ required for the soil sample,

S = weight of soil sample in gram

$0.39 = 3 \times 10^{-3} \times 100\% \times 1.3$

3 = equivalent weight of carbon

1.3 = compensation factor for the incomplete combustion of the organic matter.

3.3.1.5 Particle size analysis

The particle size distribution was determined using Robinson's method as described by ICRISAT Soil and Plant Laboratory (2013). Pre-treatment of soil sample was carried out to destroy and remove calcium carbonates, organic matter, iron oxides and soluble salts. Fifty gram (50 g) portion of air-dried soil sample were transferred into a 200 mL beaker, and 50 mL of hydrogen peroxide was added and covered with a watch glass and allowed to stand overnight. On the following day, the beaker, covered with a watch glass was placed on a hot plate until boiling for the destruction of organic matter and further treatment with deionized water was done as necessary. Excess hydrogen peroxide was eliminated by boiling more vigorously for one hour after which five drops of ammonia were added and the suspension was further boiled for another 30 minutes. The sample was transferred into a 1000 mL graduated sedimentation cylinder, and further rinses from the beaker followed by the addition of 25 mL of pyrophosphate (or sodium hexa-metaphosphate) solution and made up to 1000 mL volume with distilled water.

The clay and silt (C + S) fraction was determined by mixing the content of each cylinder using a metallic rod for 2 minutes. The eyedropper Robinson fraction C + S was taken at 10 cm deep after 3.32 minutes (corresponding to the temperature 32 °C of the suspension at 10 cm depth). The sampled fractions were put in numbered beakers of known weights. The beakers containing the pipetted suspensions were placed in an oven at 105 - 110 °C for 24 hours. The beakers were removed thereafter from the oven and immediately put in a desiccator to cool. The cooled beakers with their contents were weighed on an analytical balance of precision 0.1 mg.

The clay (C) fraction was determined using the same steps as for fraction C + S, but with a corresponding time of 2 hours 57 minutes. The suspensions were put in beakers of known weights, dried in oven at 105 - 110 °C for 24 hours after which the beakers with the dried clay content were weighed.

Calculations:

$$Clay\ (\%) = \frac{(TC_2 - TC_1) - B}{V \times W} \times 10^3 \times 10^2$$

where:

TC_1 = weight of empty beaker (g),

TC_2 = weight of beaker + dried clay (g),

B = correction factor due to the presence of sodium hexa-metaphosphate,

V = volume of pipetted fraction (mL),

P = weight of soil sample (g).

10^3 = coefficient of conversion from mL to L

10^2 = coefficient of conversion in percentage

$$Clay + Silt\ (\%) = \frac{T(C+S)_2 - T(C+S)_1 - B}{V \times W} \times 10^3 \times 10^2$$

Silt (%) = [Clay + Silt (%)] – Clay (%)

Sand (%) = 100 – Clay (%) – Silt (%)

where:

$T(C+S)_1$ = weight of empty beaker,

$T(C+S)_2$ = weight of beaker + dried clay and silt

3.3.1.6 Determination of total phosphorus

One gram (1 g) of milled straw sample was weighed into a Kjeldahl digestion flask of 75 mL (Houba *et al.*, 1995). The samples were digested with sulphuric acid (H_2SO_4) + salicylic acid + hydrogen peroxide (H_2O_2) + selenium. To determine phosphorus content, 10 mL of the digest was measured into 50 mL volumetric flask and 10 mL of vanado-molybdate solution was added. The mixture was made up to volume with distilled water and allowed to stand undisturbed for 30 minutes for colour development. A standard curve was developed concurrently with P concentrations ranging from 0.0, 5.0, 10.0, 15.0 and 20.0 mg P L^{-1}. The absorbance of the blank and the samples were read on the Colorimeter (Wagtech Projects Ltd, UK) at the wavelength of 650 nm and a graph of absorbance versus concentration (mg kg^{-1}) was plotted. The P concentrations of the blank and unknown standards were read and the mg kg^{-1} P was obtained by interpolation of the graph plotted from which concentrations were determined. P content (µg) in 1.0 gram of the plant sample was estimated as follows:

$P = C \times df$

$$\% P = \frac{C \times df}{1000000} = \frac{C \times 1000 \times 100}{1000000} = \frac{C}{10}$$

where:

C = phosphorus concentration in µg mL^{-1}, as read from the standard curve.

df = dilution factor

3.3.1.7 Determination of total potassium

The total potassium content in the supernatant digest was determined using the Jenway flame photometer (Bibby Scientific Limited, Staffordshire, UK). Standard solutions of KH_2PO_4 with concentrations of 0, 200, 400, 600, 800 and 1000 mg L^{-1} were prepared and emissions read from the flame photometer. A graph of the emissions versus concentrations of the standards was plotted from which the K concentrations in the plant samples were calculated as follows:

$$\% K = \frac{C \times df \times 100}{1000000} = \frac{C \times 100 \times 100}{1000000} = \frac{C}{100}$$

where:

C = potassium concentration in µg mL^{-1} as read from the standard curve.

df = dilution factor, which is 100 x 1 = 100

1000000 = factor for converting µg to g.

3.3.1.8 Determination of total nitrogen

The total nitrogen was determined by the Kjeldahl digestion and distillation method as described by Houba *et al.* (1995). A 1.0 g portion of soil was put into a Kjeldahl digestion flask of 75 mL then 2.5 mL of Kjeldahl catalyst (mixture of 1 part Selenium powder + 10 parts $CuSO_4$ + 100 parts Na_2SO_4) were added and mixed carefully. The stirred mixture was placed on the hot plate and heated to 100 °C, for 2 hours. The flasks were removed from the plate and allowed to cool after which, 2 mL of H_2O_2 were added then the mixture was heated again at 330 °C for four hours until clear and colourless digest was obtained. The volume of the solution was made up to 75 mL with distilled water. Clear aliquot of the sample and blank were pipetted and put into auto-analyser Technicon AAH (Pulse Instruments Ltd, Saskatoon, Saskatchewan, Canada) for the determination of total N. The percent total N was calculated as follows:

$$\% \text{ Total N} = \frac{(a - b) \times 75}{\text{weight of sample } (g) \times 10000}$$

where:

a = N content of the soil sample

b = N content of the blank

75 = final diluted volume of digest

3.3.1.9 Determination of polyphenol content

Polyphenol content was determined using the Folin-Denis method (Suzuki *et al.*, 2002). One gram portion of dried plant was weighed into 50 mL conical flasks. Then 98 % ethanol (20 mL) was added to the sample and heated at 60 °C to extract the polyphenol. The extraction was repeated after the alcohol extract was decanted into another flask. After the third extraction, the volume of the extract was made up to 50 mL by adding ethanol. Standard solutions of tannic acid (with concentrations of 0, 20, 40, 80 and 100 mg tannic acid per liter) and samples were prepared and subjected to color development.

Absorbance values of the standard and sample solutions were read on the spectrophotometer (Wagtech Projects Ltd, UK) at a wavelength of 760 nm. A standard curve was obtained by plotting absorbance values against concentrations of the standard solutions and used to determine the polyphenol contents of sample solutions. The polyphenol concentration was calculated as follows:

$$Polyphenol\ (mg/kg) = graph\ reading \times sample\ dilution \times\ aliquot\ dilution$$

where:

$$Sample\ dilution = \frac{final\ volume}{weight\ of\ sample} = \frac{50}{1}$$

Aliquot dilution = 50/1 (1 mL of initial 50 mL extract was put in a 50 mL flask and made to the 50 mL mark with ethanol i.e. 50/1).

3.3.1.10 Determination of lignin content

Lignin was determined using Acid Detergent Fiber (ADF) method described by Van Soest (1963). One gram (1 g) of milled dry plant material was weighed (W_1) into a 250 mL Erlenmeyer flask and boiled for one hour in 100 mL cetyltrimethyl ammonium bromide solution (1.0 g cetyltrimethyl ammonium bromide in 100 mL of *0.5 M* H_2SO_4) under continuous stirring. A drop of octan-2-ol was added as an antifoam agent. The solution was filtered over an ignited and pre-weighed sinter and washed 3-times with 50 mL of hot distilled water. The filtrate was washed with acetone until further decoloration was not observed. The filtrate was dried for 2 hours at 105 °C followed by the addition of about 10 mL of cool 72 % H_2SO_4 (15 °C) to the cooled sinter and mixed with the filtrate. Draining acid was refilled and the mixture was kept for 3 hours in 72 % H_2SO_4. Thereafter, the acid was filtered off under vacuum, and the residue was washed with hot distilled water until it was acid-free. The sinter was dried at 105 °C for 2 hours, cooled, and weighed (W_2). The sinter was ignited at 500 °C for 2 hours, cooled, and weighed to determine ash content of the residue (W_3). The percent lignin (%) was calculated as follows:

$$\% \ Lignin = \frac{(W_2 - W_3)}{W_1} \times 100$$

3.3.1.11 Contribution of termites to decomposition

The termites population in litterbags was assessed according to the method developed by Tropical Soil Biology and Fertility (TSBF) and described by Bignell and de Souza Moreira (2008). The termites collected were counted by hand. The contribution of termite to the decomposition of organic material was calculated using the formula giving by (Mando and Brussaard, 1999) as follows:

$$Termite\ contribution\ (\%) = \left(\frac{A - B}{100 - B}\right) \times 100$$

where:

A = percentage of organic material remaining in the litterbags without insecticide

B = percentage of organic material remaining in the litterbags with insecticide

3.3.2 Data collection and statistical analysis

The data collected were processed using Excel software. Prior to the analysis, the data were carefully checked for homogeneity of variance and normality. The analysis of variance of the data was done using the AREPMEASURES procedure in GENSTAT (Fatondji *et al.,* 2009). Differences were reported as significant if the probability was less than 0.05. Decomposition and nutrient loss constants, k, was determined for dry mass and nutrients for each organic material by the single exponential model described by Wider and Lang (1982) as follows:

$$Y_t = Y_0 e^{-kt}$$

where:

Y_0 = initial percent mass of organic material;

Y_t = percent mass of organic material remaining at time t;

t = time (weeks);

k = decomposition or release constant.

In order to identify the factors that contribute to the decomposition of organic material, principal component analysis, as a multivariate analytical tool, was performed using GENSTAT software packages (Trust, 2007).

CHAPTER FOUR

4.0 RESULTS

4.1 Rainfall distribution and temperature

The daily rainfall and average temperature during the experimental period is shown in Fig. 2. The total annual rainfall recorded over the growing period was 689 mm. Minimum and maximum temperatures were 23 °C and 30 °C, respectively.

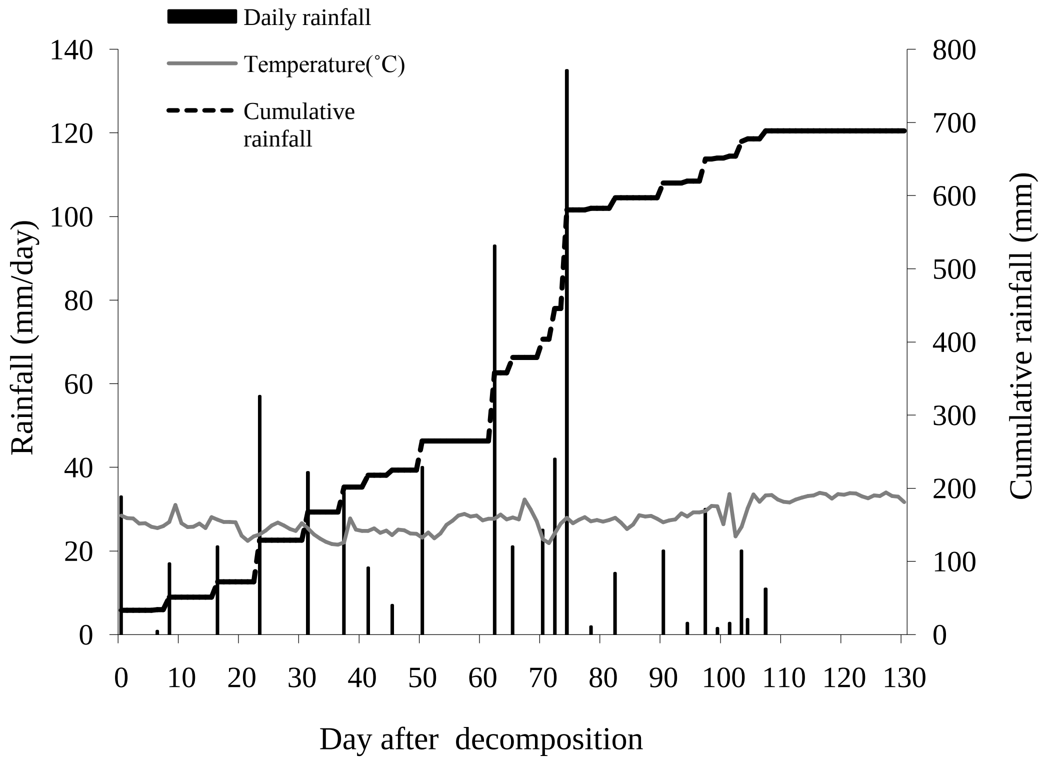

Figure 2: Rainfall distribution and temperature regime of the experimental site

4.2 Some physical and chemical properties of the experimental soils

The physico - chemical properties of the soil at the experimental sites is presented in Table 4.1. The highest clay (10 %) and silt (11 %) contents were determined for the crusted soil while the highest sand content (95 %) was observed in sandy soil. The organic carbon content (0.2 %) was similar for both soil types. The crusted sandy soil was slightly more acid (pH = 3.9) than that of the sandy soil (pH = 4.4).

Table 4.1: Initial soil carbon and texture of the experimental sites

Parameters	**Sandy soil**	**Crusted sandy soil**
Sand (%)	94.6	79.1
Silt (%)	2.2	11.3
Clay (%)	3.2	9.6
pH (1:2.5 H_2O)	4.4	3.9
Organic carbon (%)	0.2	0.2

4.3 Initial chemical properties of the organic materials

The chemical composition of the organic materials prior to decomposition is presented in Table 4.2. There was a significant difference in nitrogen (N) content among the organic materials ($P < 0.001$). The highest N content was recorded for *Acacia tumida* pruning (2.3 %) followed by cattle manure (1.5 %). Phosphorus (P) content was significantly ($P < 0.001$) higher in cattle manure (0.34 %) compared with millet straw (0.1 %) and *Acacia tumida* pruning which recorded a P value of 0.14 percent. The potassium (K) content was significantly different ($P < 0.001$) among the organic amendments. The highest K content was obtained in millet straw (1.8 %) followed by *Acacia tumida* (1.5 %) while the lowest K content was recorded for cattle manure (0.7 %). The highest C/N ratio was observed in millet straw (63.9) followed by that of cattle manure (29.7).

Table 4.2: Initial chemical properties of the organic amendments

Parameters	***A. tumida* pruning**	**Millet straw**	**Cattle manure**	***cv %***	***F pr.***	**Lsd (0.05)**
Nitrogen (N) (%)	2.3	0.8	1.5	7.2	< 0.001	0.217
Phosphorus (%)	0.1	0.1	0.3	2.8	< 0.001	0.009
Organic carbon (%)	50.3	50.5	44.5	3.7	0.043	5.018
Polyphenol (P) (%)	1.3	0.6	0.7	8.9	< 0.001	0.154
Potassium (K) (%)	1.5	1.8	0.7	2.3	< 0.001	0.060
Lignin (L) (%)	21.9	7.7	11.8	11.6	< 0.001	3.192
C/N ratio	22.2	63.9	29.7	4.6	< 0.001	3.534
N/L ratio	0.1	0.1	0.1	15.9	0.153	0.035
P/L ratio	0.01	0.01	0.02	17.7	0.08	0.024

4.4 Decomposition coefficient *(k)* and decomposition rate patterns of organic materials

The decomposition coefficients (*k*) of organic amendments are presented in Table 4.3. The decomposition coefficients were significantly different (P < 0.001) among the organic materials. The highest decomposition coefficient was recorded for *Acacia tumida* pruning (*k/day* = 0.014) followed by cattle manure (*k/day* = 0.012).

The application of insecticide had a significant (P < 0.001) effect on the decomposition coefficient of the organic materials. The lowest decomposition coefficient was observed in the litterbags treated with the insecticide (*k/day* = 0.009) compared with those of litterbags without insecticide (*k/day*= 0.013). However, the soil type had no significant effect on the decomposition coefficient.

Table 4.3: Decomposition coefficient (*k)* values of treatments

Treatments	***k/day* values**
Organic materials	
Cattle manure	0.012
Millet straw	0.008
Acacia tumida pruning	0.014
Type of soil	
Crusted sandy soil	0.011
Sandy soil	0.011
Insecticide	
Without insecticide	0.013
With insecticide	0.009
F.pr	
Organic materials (O)	< 0.001
Type of Soil (S)	0.779
Insecticide (I)	< 0.001
O x S	0.621
O x I	0.17
S x I	0.114
O x S x I	0.978
CV (%)	26.8

At 126 days of decomposition which coincided with the end of the rainy season, only 55 % of *Acacia tumida*, 59 % of manure and 62 % of millet straw remained in the litterbags (Fig. 3). The rate of organic material disappearance was relatively higher for *Acacia tumida* compared with that of cattle manure and millet straw. There were significant differences ($P < 0.001$) in decomposition rates among the organic materials.

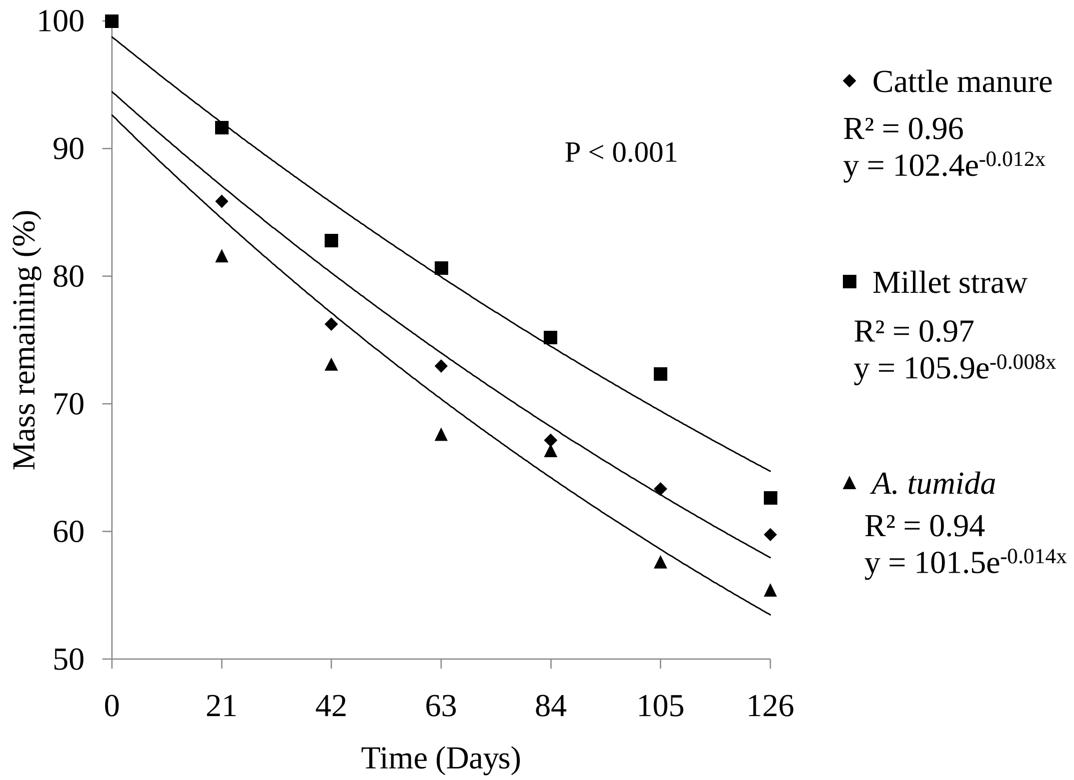

Figure 3: Decomposition patterns of organic amendments. Lines indicate best fit

The decomposition rate was relatively faster in sandy soil whereas the highest decomposition rate was recorded for crusted sandy soil toward the end of the experiment. However, the difference in decomposition rates was not significant between the two soil types (Fig. 4).

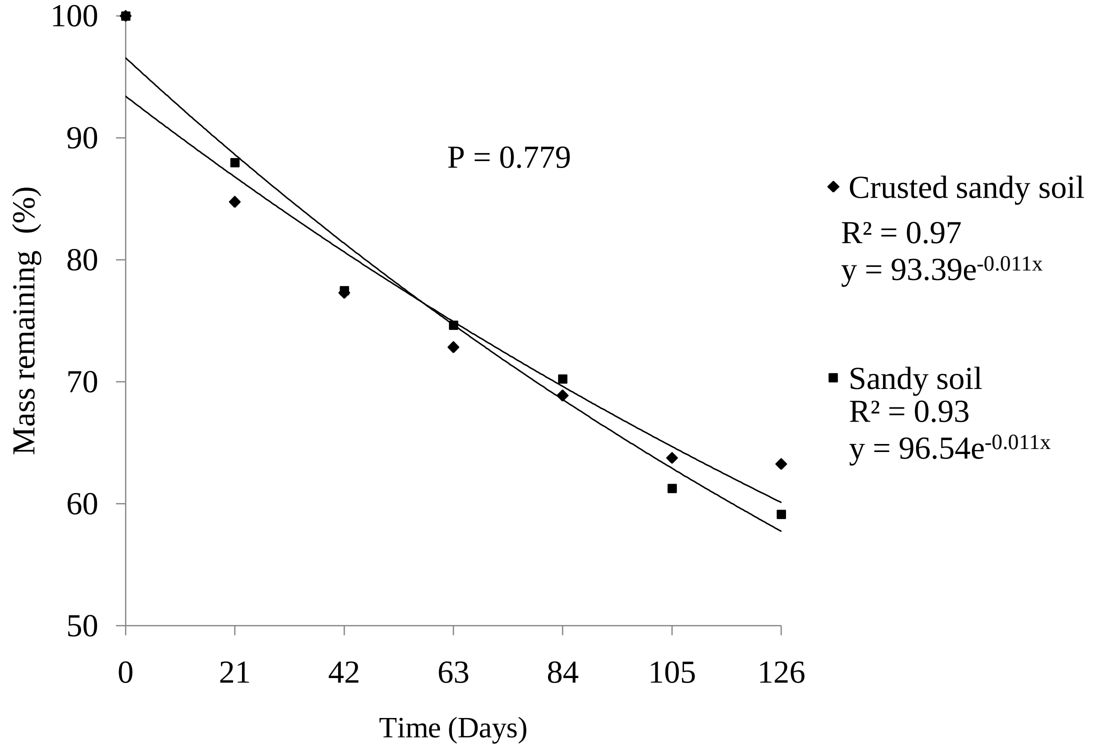

Figure 4: Effect of soil type on decomposition of organic amendments. Lines indicate best fit

Application of insecticide to the organic material in the litterbags significantly ($P < 0.001$) affected the rate of decomposition. The highest decomposition rate was documented for the litterbags without insecticide application (Fig.5). Generally, 45 % of organic amendments decomposed in the non-insecticide treated litterbags while 34 % of decomposition was observed in insecticide treated litterbags.

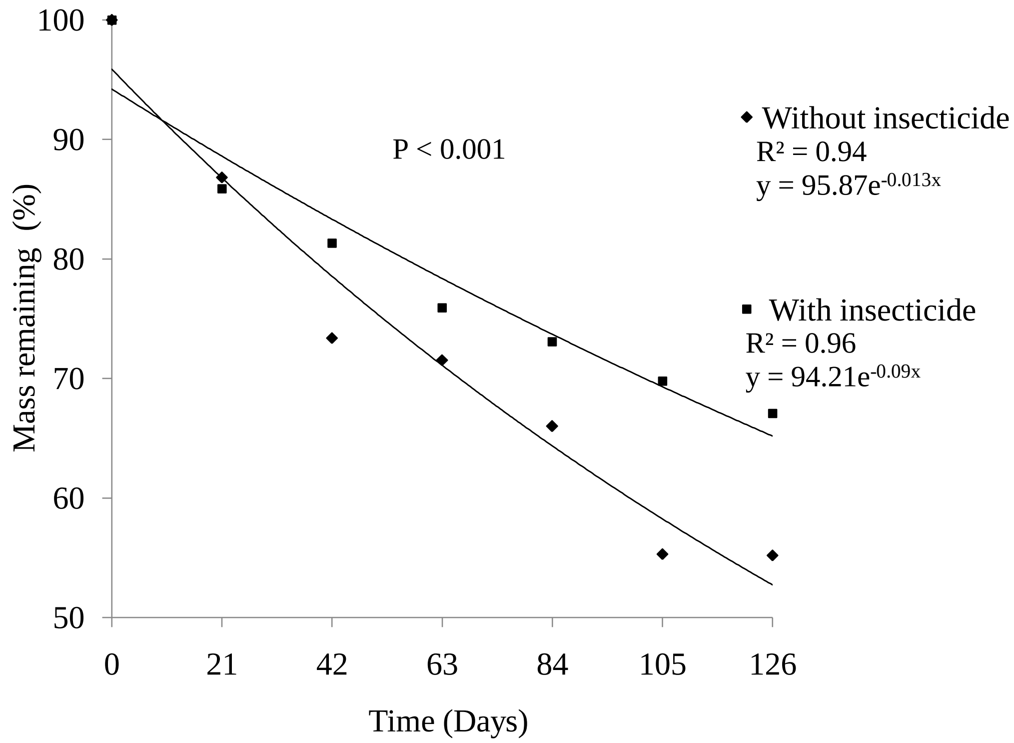

Figure 5: Effect of insecticide application on decomposition rate. Lines indicate best fit

4.5 Dynamics of termite population during organic matter decomposition

Termite population varied with type of organic material (Table 4.4). The presence of termites was significantly ($P < 0.001$) affected by the type of organic materials. The termite population was estimated to be 106 and 104 for millet straw and cattle manure filled litterbags respectively, while the lowest termite population (4) was recorded for *Acacia tumida* prunings. The application of insecticide depressed significantly termite populations in the litterbags. There was a significant interaction between the type of organic material and insecticide application on termite population. It is worthy to note that the termite population was consistently and significantly low in the *Acacia tumida* litterbags regardless of insecticide application but population of termite also varied significantly ($P = 0.006$) with type of soil. The highest population of termites was observed on sandy soil while the lowest termite population was observed on the crusted sandy soil (Table 4.4).

Table 4.4: Effect of type organic material and insecticide application on termite population

Treatments	Termites population		
	Without insecticide	**With insecticide**	**Mean**
Organic materials			
Cattle manure	106	2	54
Millet straw	104	6	55
Acacia tumida pruning	4	1	2
Soil type			
Sandy soil	98	3	56
Crusted sandy soil	44	3	24
F pr.			
Organic materials	< 0.001		
Soil type	0.006		
Insecticide	< 0.001		
Organic materials x insecticide	< 0.001		
Soil type x insecticide	0.005		

The contribution of termite to organic material disappearance was significantly different (P = 0.019) among the organic materials (Table 4.5). The highest termite population was observed on millet straw litterbags (36 ± 5 %) followed by manure (30 ± 8 %) whereas the lowest termite activity was recorded for *Acacia tumida* litterbags. On other hand, the type of soil did not significantly affect the contribution of termites to decomposition. Yet, the highest contribution of termite to the decomposition of organic material was observed on sandy soil (30 %) compared to 20 % on crusted sandy soil.

Table 4.5: Effect of termite population and soil type on decomposition

Treatments	**% Contribution of termites**
Organic materials	
Cattle manure	29.5 ± 7.6
Millet straw	35.9 ± 4.5
A. tumida pruning	8.9 ± 4.8
Soil type	
Sandy soil	29.9
Crusted sandy soil	19.6
F pr.	
Organic materials	0.019
Soil type	0.163
Organic materials x soil type	0.970

± Standard error of mean

No termites were observed in the organic materials during the first 21 days of decomposition (Fig. 6). However, at 42 days, termites colonized the litterbags and contributed on average to 32 % of decomposition regardless of soil type and organic material quality. Within the period of 63 to 84 days of decomposition, the population of termites decreased and led to a reduction in termite contribution to the organic material disappearance ranging from 17 to 20 percent. Nevertheless, during the last

105 and 126 days of decomposition, termites colonized the litterbags and contributed to 27 and 33 % of decomposition respectively at 105 and 126 days.

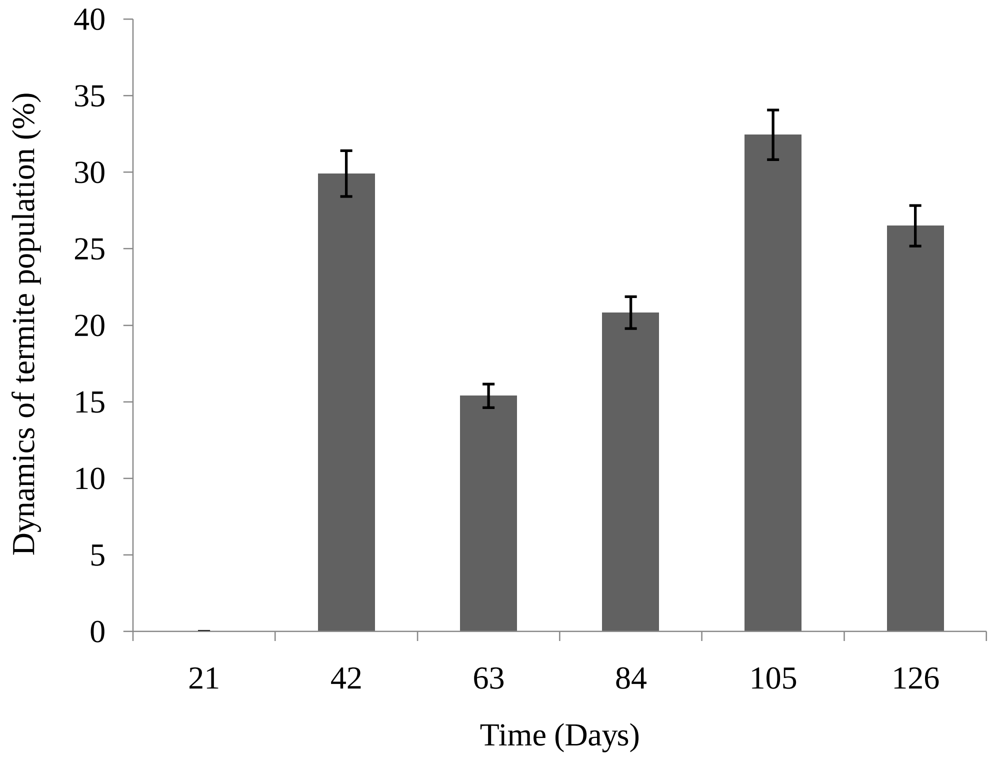

Figure 6: Dynamics of termite population during decomposition. Bars represent standard error of mean

4.6 Factors influencing the decomposition of organic materials

The principal component analysis was used to identify the most important variables that exert significant influence on the decomposition/disappearance of organic materials (Table 4.6.). Factor 1 accounted for 84 % of the total variance. Termite population (0.82), C/N ratio (0.52) and lignin concentration (0.21) showed high positive loadings indicating that termites and C/N are important factors that influence organic material decomposition in the study area.

Table 4.6: Factor loading for organic material decomposition

Parameters	Principal components	
	Factor 1	Factor 2
Carbon : nitrogen ratio	**0.52507**	**0.82418**
Termite population	**0.82442**	**0.51982**
Lignin	**0.20903**	0.00001
Nitrogen	0.02051	0.01060
Organic carbon	0.02040	**0.22032**
Potassium	0.00083	0.03686
Polyphenol	0.00969	0.00388
Phosphorus	0.00001	0.00635
Nitogen : lignin ratio	0.00008	0.00091
Polyphenol : lignin ratio	0.00014	0.00049
Eigenvalues	1.61	1.65
Variance (%)	84.2	15.8
Cumulative explanation (%)	84.2	100

4.7 Nitrogen, phosphorus and potassium release patterns of the organic amendments

4.7.1 Effect of type of organic amendment on N, P and K decomposition coefficients

There were significant differences in *k* constant of nutrients released from the organic materials (P < 0.001). The highest *k* constant for N release was obtained for millet straw (*k*/day = 0.025) the similar *k* constant values for N release (*k/day* = 0.017) were recorded for manure and *Acacia tumida* (Table 4.7). The highest *k/day* constant for potassium (K) release was documented for *Acacia tumida* (*k/day*= 0.114) followed by cattle manure (*k/day* = 0.113). Conversely, millet straw recorded the lowest *k* constant for phosphorus (P) release (*k/day* = 0.016) compared with cattle manure (*k/day* = 0.035) and *Acacia tumida* pruning (*k/day* = 0.020).

Table 4.7: Nitrogen, phosphorus and potassium release coefficients (*k)*

	k/day constant values of N, P and K released		
Organic Materials	**N**	**P**	**K**
Cattle manure	0.017	0.035	0.113
Millet straw	0.025	0.016	0.099
A. tumida pruning	0.017	0.020	0.114
F. pr.			
Organic materials	0.001	< 0.001	< 0.001

4.7.2 Nitrogen release patterns of organic materials

The rate of N released from organic amendments increased more rapidly from 21 days to 105th days after decomposition and was significantly different among the organic materials (P < 0.001). However, after 126 days of decomposition, N release decreased in all the organic materials (Fig. 7). At 84 days decomposition corresponded to the peak of N release period, the N release represented 44 %, 40 % and 28 %, respectively for millet straw, manure and *Acacia tumida.*

4.7.3 Phosphorus release patterns of organic materials

There were significant differences in P release (P < 0.001) from the different organic materials (Fig. 8). The rate of P release was highest in cattle manure (60 %) during all sampling periods. The release of P did not show a clear trend for *Acacia tumida* and millet straw. However, at 105 days, a higher P release was recorded for *Acacia tumida* (52 %) compared to millet straw (33 %).

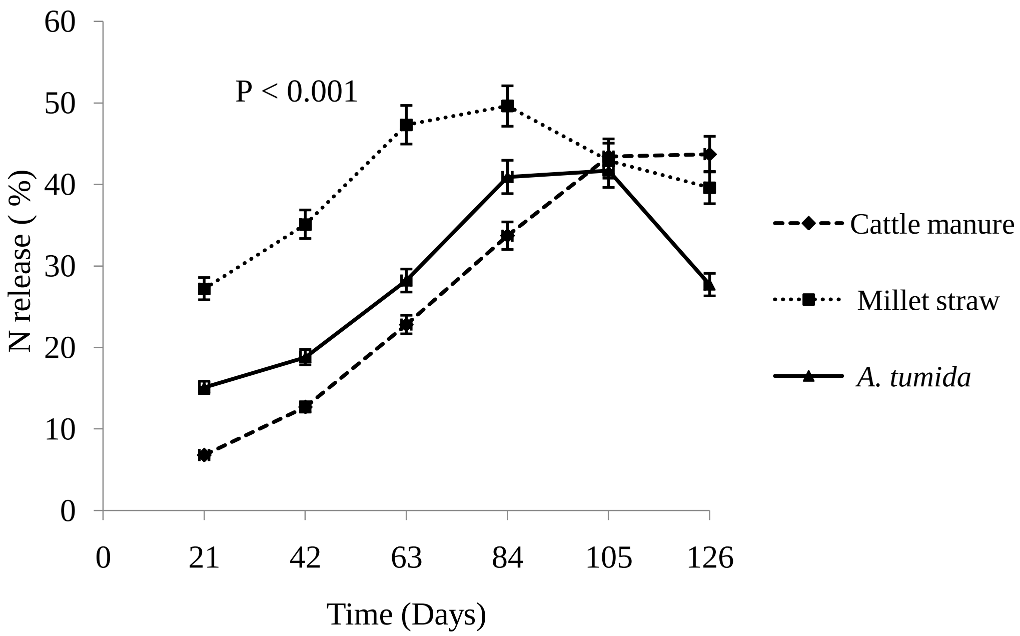

Figure 7: Nitrogen release pattern of organic amendments. Bars represent standard error of mean

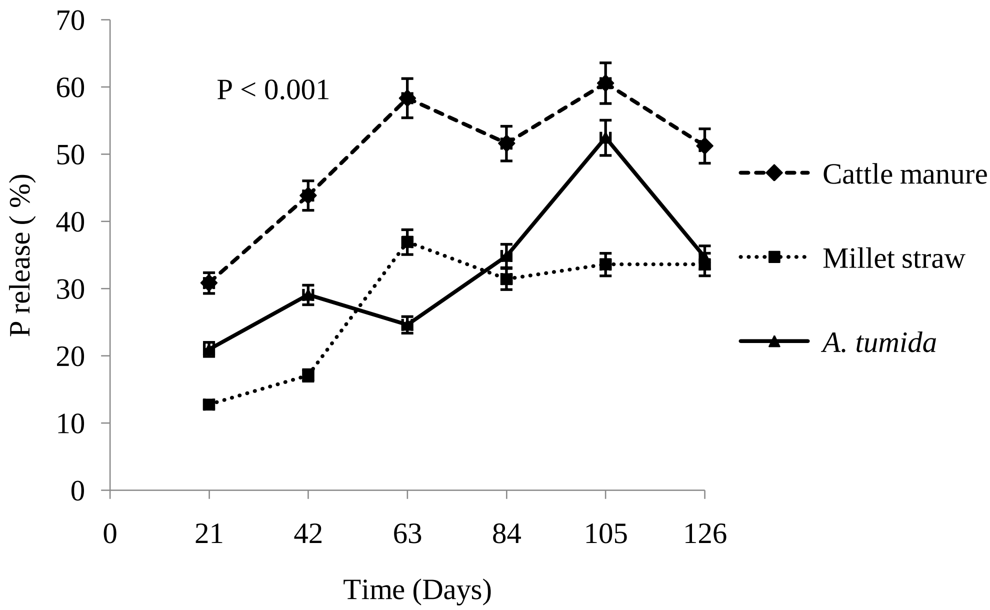

Figure 8: Phosphorus release pattern of organic amendments. Bars represent standard error of mean

4.7.4 Potassium release patterns of organic materials

Potassium release patterns from the different organic materials are as shown in Fig. 9. The potassium (K) release pattern was significantly different (P < 0.001) among the organic materials. At 126 days of decomposition, the highest K (95 %) released over the period was observed.

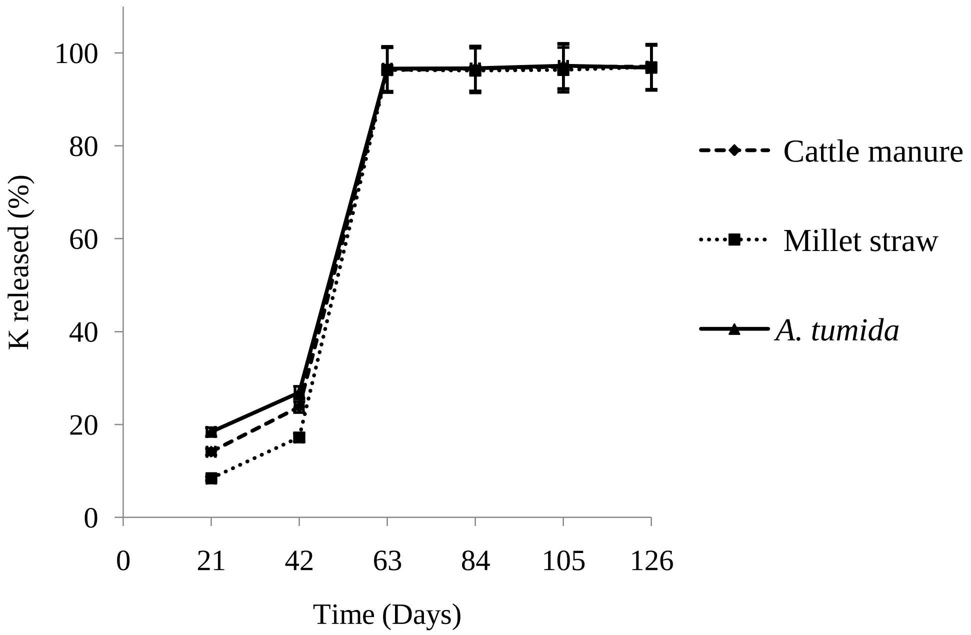

Figure 9: Potassium release pattern of organic amendments. Bars represent standard error of mean

4.8 Effect of insecticide application on nutrient release coefficient (*k*)

There were significant differences (Table 4.8) in *k* constant of nutrient (N, P and K) release from organic materials treated with insecticide (P < 0.001). In general, higher *k* constants for nutrient release were obtained in litterbags not treated with insecticide relative to those treated with insecticides.

Table 4.8: Effect of insecticide application on nutrient release coefficients (*k)*

	k/day values of nutrients released		
Pesticide	N	P	K
Without insecticide	0.024	0.027	0.113
With insecticide	0.017	0.021	0.110
F.pr	0.001	< 0.001	0.008
s.e.d (5%)	*4.75*	*2.231*	*0.820*

4.8.1 Effect of insecticide application on N, P and K release patterns

4.8.1.1 Nitrogen release pattern

Nitrogen release pattern throughout the decomposition study is as shown in Fig. 10. Nitrogen release was significantly (P = 0.001) reduced by the insecticide application regardless of the type of organic material. A higher N release (52 %) was recorded for the untreated insecticide litterbags after 105 days of decomposition while a lower N release of 33 % was obtained for the litterbags treated with insecticide.

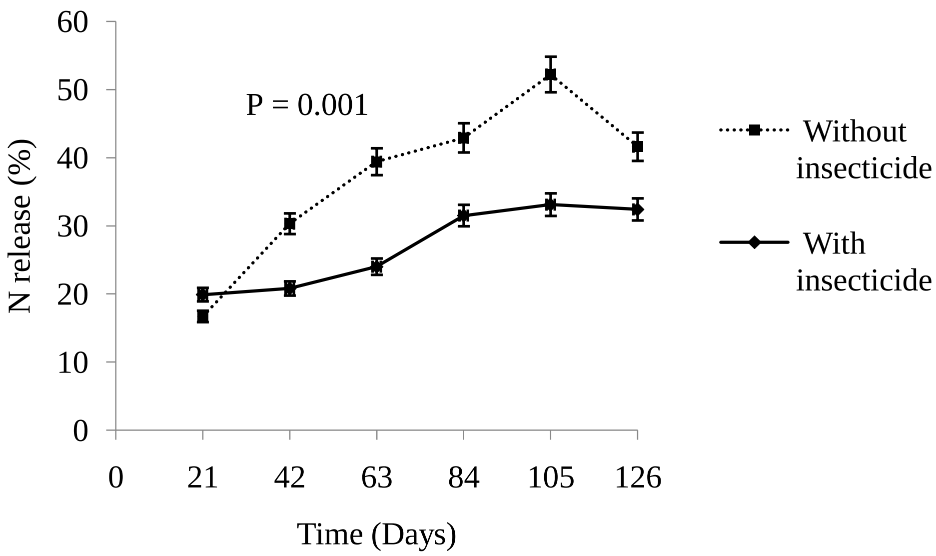

Figure 10: Nitrogen release pattern of insecticide treated organic amendments. Bars represent standard error of mean

4.8.1.2 Phosphorus release pattern

The application of insecticide significantly ($P < 0.001$) reduced P release. The release of P was higher in the litterbags where the insecticide was not applied relative to that of insecticide treated litterbags (Fig. 11). The maximum P released was observed during the 105th day decomposition with 52 % and 42 % of P released from litterbags free of insecticide and those treated with insecticide, respectively.

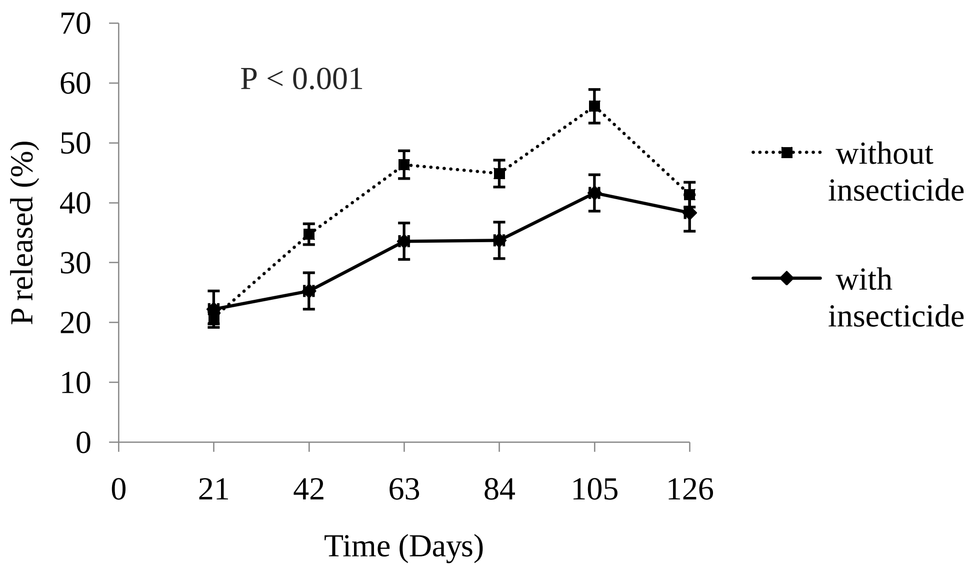

Figure 11: Phosphorus release pattern of insecticide treated organic amendments. Bars represent standard error of mean

4.8.1.3 Potassium release pattern

The rate of K release throughout the decomposition study is illustrated in Fig. 12. Unlike N and P, the application of insecticide did not influence significantly the release of K during the experimental period.

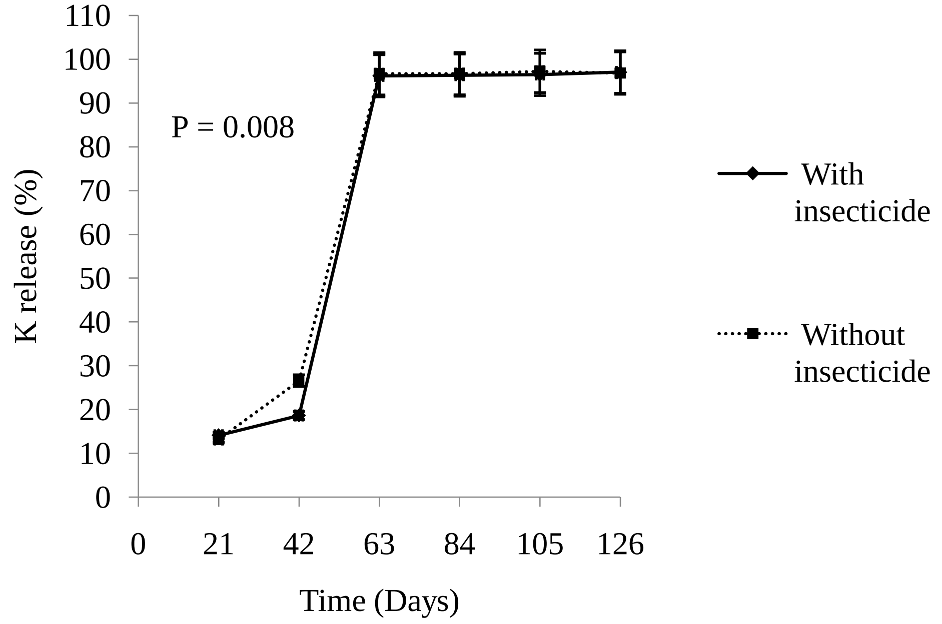

Figure 12: Potassium release pattern of insecticide treated organic amendments. Bars represent standard error of mean

CHAPTER FIVE

5.0 DISCUSSION

5.1 Biochemical properties of organic materials on decomposition

The decomposition of an organic material is known to be controlled by three main processes: chemical, physical, and biochemical. Among the biochemical characteristics of an organic material, C/N ratio exerts a great influence on its decomposition rate (Palm and Sanchez, 1991). A material with lower C/N ratio would be much easier to be decomposed by the micro-organisms. In this current study, the highest decomposition rate was documented for *Acacia tumida* prunings which also had a lowest C/N ratio of 22. This finding support the previously reported pattern that an organic material of high quality (characterized by higher N concentration and lower C/N ratio) could decompose faster compared to low quality organic material (Sanchez, 2001). Although C/N ratio is important, it appears that it was not the sole factor that governed the decomposition of the organic materials. Ayuke *et al.* (2011) reported that, the initial N content of organic materials play an important role on decomposition due its contribution to meet nitrogen needs of decomposers at the initial stage of the decomposition. The highest N content of *Acacia tumida* (Table 4.2) probably played a crucial role in accelerating the decomposition of this organic material. The lowest decomposition rate recorded for millet straw could be attributed to its relatively low content of N (0.8 %) and high C/N ratio (64 %). However, the principal component analysis (Table 4.6) revealed that N and C contents of the organic materials were less influential on the decomposition rate than C/N ratio. Studies have shown that the stoichiometry of the organic material being decomposed is a determinant of how much CO_2 would be released during decomposition (Manzoni *et al.*, 2008). According to these studies, micro-organisms have a fixed nutrient ratio (C/N and C/P) and, during the decomposition process they impose their own stoichiometry to the transformed material. This implies that, a diet rich in C causes microorganisms to release more C as CO_2 into the atmosphere as the microbes try to maintain their healthy C/nutrient ratios (Manzoni *et al.*, 2008; Manzoni *et al.*, 2010). However, in this current study, the CO_2 released during the decomposition was not measured in order to confirm previously reported observations. Nevertheless, it appears that the high C content of *Acacia tumida* had increased its decomposition by the micro-organisms. On the other hand, the high content of lignin was reported to decrease the decomposition rate of an organic material (Palm and Sanchez, 1991). However, the high content of lignin in *Acacia tumida* leaves (20 %) compared with the lignin concentration of the other organic materials used in this current study did not reduce the decomposition rate of this organic material. It appears therefore that among the biochemical properties of *Acacia tumida* pruning, N concentration had a strong influential effect on its decomposition rate.

5.2 Effect of soil type on decomposition

The type of soil did not affect significantly the decomposition of organic materials used in the current study (Table 4.5). However, the decomposition rate was slightly higher in sandy soil compared to crusted soil. The relatively higher decomposition rate of organic material observed on sandy soil can be attributed to higher termite presence recorded (Table 4.5). However, the current finding does not support the previous findings of Esse *et al.* (2001) who reported highest manure disappearance on crusted soil compared to sandy soil due to higher termites activity. The presence of termites on crusted soil is attributable to the heavy soil texture favourable for termite mound establishment. An earlier study by Bachelier (1978) showed that 10 % of clay and silt contents were required for successful termite mound formation. In this study, this requirement was only satisfied on crusted soil with about 20 % of clay and silt contents. Although, the results reported in this study differed from those published by Esse *et al.* (2001), the current results are consistent with those reported by Epstein *et al.* (2002) who observed an increment in organic material decomposition with decreasing soil clay content. All the same, it could be speculated that the higher decomposition rate observed in the sandy soil could be attributed to the amelioration of soil moisture conditions which improved macro-fauna (termites) and microbial activities thereby increasing organic material decomposition process (Riutta *et al.*, 2012).

5.3 Contribution of termites to the decomposition of organic amendments

The results obtained in this study showed that the presence of termites significantly affected the rate of decomposition of organic materials regardless of the type of organic material. The highest decomposition coefficient (*k/day*) was recorded for the litterbags which were not treated with insecticide (Table 4.3). This finding is in agreement with the results reported by Esse *et al.* (2001) who observed that the presence of termites increases decomposition. On the average, the contribution of termites to decomposition was estimated to be 35 % regardless of the type on the organic amendments. Termites contribution to the decomposition of organic material recorded in this study was less than 80 % of termites contribution to the breakdown of straw reported by Mando and Brussaard (1999). However, the percent contribution of termites (35 %) to the organic material decomposition obtained in the current study is within the range of the values reported by Slade and Riutta (2012) who found that the faunal effect on organic material decomposition ranges from 22 to 44 percent.

There was a significant difference in termites activity among the organic materials used in this study. The highest contribution of termites to the decomposition of organic material was recorded for millet straw (36 %) followed by cattle manure (30 %) while the least was observed in *Acacia tumida* (9 %). The lowest contribution of termites to *Acacia tumida* decomposition could be probably due to the preference of termites for millet straw and cattle manure in comparison with *Acacia tumida.* According to Higashi *et al.* (1992), termites in general nourish on dead plant material that has a C/N ratio much higher than their own tissues in order to balance their carbon and nitrogen inputs. An earlier study, reported C/N ratio of 4 to 12 for termite tissues (Matsumoto, 1976). The C/N ratios of the organic materials used in this study (Table 4.2) were markedly greater than those of termites' tissues which indicated that all these materials were attractive to the termites. If the hypothesis of Higashi *et al.* (1992) has to be held true, the minimal presence of termites in *Acacia tumida* litterbags seems to be unclear because of the highest C/N ratio of this material (22) compared to C/N ratio of termites tissues. Moreover, Mando and Brussaard (1999) reported that the dominant termite species in the Sahel is *Macro-termitinae*, and they are less affected by the quality of their food because of their symbiotic relationship with *Basidiomycete* fungi. It seems therefore possible that the limited number of termites on *Acacia tumida* pruning resulted from the foraging behaviour of termites which favoured the preference of millet straw and cattle manure over *Acacia tumida* prunings. Nonetheless, a further study is required to clarify the foraging behaviour of termites in relation to the biochemical properties of the organic material.

5.4 Nutrient release patterns of the organic amendments

All the organic materials showed increased N release during the decomposition study. At the end of the decomposition study, millet straw released 51 % of its initial N content followed by *Acacia tumida* with 41 % of N released. The results on N release obtained in this study do not support the earlier studies by Gnankambary (2007); Mafongoya *et al.* (1997) who reported that the highest N release was expected from the organic material with high quality (high initial N content, low C/N ratio). The differences in polyphenol content of the organic materials used could explain the N release rate pattern observed in this study (Handayanto *et al.*, 1997).
Phosphorus release from the organic materials was rapid from the initial stages of decomposition. However, after fifteen weeks, there was a decrease in P release in all the organic materials which could be explained by the decrease in soil moisture content during this period (Fig. 2). Mineralization of organic P is facilitated by micro-organisms and the rate and pattern are controlled by the environmental conditions. According to Kabba and Aulakh (2004), the changes in soil moisture content influence microbial activity and thereby affect P mineralization. The highest P release was observed with manure. This could be attributed to the highest initial P content of manure (0.3 %) compared with those of millet straw (0.1 %) and *Acacia tumida* pruning (0.1 %). The same observations were made by Arthur (2009) who reported higher P release from manure compared with crop residue due its high initial P content. Furthermore, Kwabiah *et al.* (2003) reported that phosphorus release pattern during decomposition was positively correlated with the initial P content.

Potassium release was more rapid (Fig. 9) than N and P release. Rapid K release from organic materials is frequently reported during mineralization (Bayala *et al.*, 2005; Fatondji *et al.,* 2009; Tian *et al.,* 1992). The rapid K release in this study could be attributed to high mobility of K which makes it more accessible to leaching. According to Tian *et al.* (1992), the rapid organic K mineralization was explained by the fact that K release is less affected by the chemical properties of the organic material, soil chemical properties, and soil faunal activities than N and P release.

5.5 Effect of insecticide application on N, P and K release

The application of insecticide significantly impacted on nutrient (N, P and K) release rates regardless of the type of organic material. The highest proportion of nutrients released was documented for the litterbags which were not treated with insecticide (Table 4.8). The presence of termites increased the organic material comminution thereby increasing their accessibility to the microorganisms responsible for mineralization. Earlier studies have reported that soil fauna are crucial for decomposing and comminuting (i.e. reduction in the size of organic material due to feeding) the organic material at the initial stages of decomposition which consequently increase the surface area available to the micro flora and thereby increase the cycling of nutrients in soils (Gnankambary, 2007; Sylvia *et al.,* 2005).

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The decomposition of an organic amendment is important for increasing plant nutrient availability in the Sahelian low-input farming systems. Based on the objectives and the results obtained in the current study, the following conclusions can be drawn:

i. The pruned leaves of *Acacia tumida* have high nutrient content particularly N (2.3 %) relative to the commonly used soil organic amendments (animal manure and crop residues) for soil fertility improvement in Niger. Nitrogen content of *Acacia tumida* pruning was superior than the critical level of 2.0 to 2.5 % below which net N immobilization from the soil would be expected. Moreover, polyphenol level (1.3 %) of *Acacia tumida* prunings was lower than the critical value of 4 %.

ii. Intrinsic organic material qualities notably C/N ratio, lignin and carbon contents strongly influenced the decomposition and amount of nutrients released from the organic amendments. *Acacia tumida* prunings decomposed faster (k = 0.014) compared to millet straw (k = 0.008) and cattle manure (k = 0.012).

iii. The results obtained in this study showed that the presence of termites significantly affected the rate of decomposition of organic materials. The contribution of termites to decomposition was estimated to be 35.9 %, 29.5 % and 8.9 %, respectively for millet straw, manure and *Acacia tumida* prunings. The limited termite population on *Acacia tumida* prunings resulted from the foraging behaviour of termites which favoured the preference of millet straw and manure over *Acacia tumida* prunings.

Hence, studies aimed at clarifying the foraging behaviour of termites in relation to the biochemical properties of the organic material need to be undertaken.

iv. Soil texture did not appear to exert significant influence on the decomposition of organic materials in Sahelian environment of Niger.

6.2 Recommendations

1. *Acacia tumida* prunings could be used as source of nutrient for soil fertility improvement in the biomass-scarce zone of Niger.

2. Further research should be undertaken to synchronize nutrient release from *Acacia tumida* prunings and crop nutrient demand for increased crop production in the low-input cropping systems.

3. The comminution of organic material through termite activity should be encouraged to facilitate the microbial activity responsible for nutrient cycling.

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APPENDICES

Appendix 1: Litterbag containing *Acacia tumida* prunings

Appendix 2: Litterbag containing millet straw

Appendix 3: Litterbag containing cattle manure